

2m4  
"Made available under NASA sponsorship  
in the interest of early and wide dis-  
semination of Earth Resources Survey  
Program information and without liability  
for any use made thereof."

E7.4-10411

CR-137256

CRUSTAL EXTENSION AND TRANSFORM FAULTING IN THE  
SOUTHERN BASIN RANGE PROVINCE

Argus Exploration Company  
555 South Flower Street - Suite 3670  
Los Angeles, California 90071

March 1974  
Report of Investigation

Prepared for  
GODDARD SPACE FLIGHT CENTER  
Greenbelt, Maryland 20771

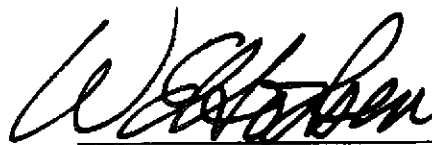
(E74-10411) CRUSTAL EXTENSION AND  
TRANSFORM FAULTING IN THE SOUTHERN BASIN  
RANGE PROVINCE (Argus Exploration Co.,  
Los Angeles, Calif.) 54 p HC \$5.75

N74-19946

Unclas

32 CSCL 08G G3/13 00411

Approved by



W. E. Hosken  
President

<b>BIBLIOGRAPHIC DATA SHEET</b>	1. Report No.	2.	3. Recipient's Accession No.
4. Title and Subtitle		5. Report Date	
CRUSTAL EXTENSION AND TRANSFORM FAULTING IN THE SOUTHERN BASIN RANGE PROVINCE		March 1974	
7. Author(s)		8. Performing Organization Rept. No.	
Mark A. Liggett and John F. Childs			
9. Performing Organization Name and Address		10. Project/Task/Work Unit No.	
Argus Exploration Company 555 South Flower Street - Suite 3670 Los Angeles, California 90071			
12. Sponsoring Organization Name and Address		11. Contract/Grant No.	
National Aeronautics and Space Administration Goddard Space Flight Center Greenbelt, Maryland 20771		NAS 5-21809	
		13. Type of Report & Period Covered	
		Report of Investigation	
15. Supplementary Notes		14.	
16. Abstracts Field reconnaissance and study of geologic literature guided by analysis of ERTS-1 MSS imagery have led to a hypothesis of tectonic control of Miocene volcanism, plutonism and related mineralization in part of the Basin Range Province of southern Nevada and northwestern Arizona. The easterly trending right-lateral Las Vegas Shear Zone separates two volcanic provinces believed to represent areas of major east-west crustal extension. One volcanic province is aligned along the Colorado River south of the eastern termination of the Las Vegas Shear Zone; the second province is located north of the western termination of the shear zone in southern Nye County, Nevada. Geochronologic, geophysical and structural evidence suggests that the Las Vegas Shear Zone may have formed in response to crustal extension in the two volcanic provinces in a manner similar to the formation of a ridge-ridge transform fault, as recognized in ocean floor tectonics.			
17. Key Words and Document Analysis. 17a. Descriptors			
Tectonics Transform faults Basin Range Province Las Vegas Shear Zone Volcanics Gold mineralization ERTS-1 MSS Imagery			
17b. Identifiers/Open-Ended Terms			
17c. COSATI Field/Group			
18. Availability Statement		19. Security Class (This Report)	21. No. of Pages
Release unlimited		UNCLASSIFIED	
		20. Security Class (This Page)	22. Price
		UNCLASSIFIED	

# CRUSTAL EXTENSION AND TRANSFORM FAULTING IN THE SOUTHERN BASIN RANGE PROVINCE

Mark A. Liggett and John F. Childs  
Argus Exploration Company  
Los Angeles, California

## ABSTRACT

Field reconnaissance and study of geologic literature guided by analysis of ERTS-1 MSS imagery have led to a hypothesis of tectonic control of Miocene volcanism, plutonism, and related mineralization in part of the Basin Range Province of southern Nevada and northwestern Arizona.

The easterly trending right-lateral Las Vegas Shear Zone separates two volcanic provinces believed to represent areas of major east-west crustal extension. One volcanic province is aligned along the Colorado River south of the eastern termination of the Las Vegas Shear Zone. This province is dominated by large granitic plutons and related silicic to intermediate volcanics of Miocene age. Dike swarms, elongated plutons, and normal faults of major displacement are oriented with northerly trends. The second volcanic province is located north of the western termination of the Las Vegas Shear Zone in southern Nye County, Nevada. This area is characterized by silicic to intermediate volcanics, plutons, dikes, and northerly striking normal faults similar to those in the volcanic province south-east of the Las Vegas Shear Zone.

Geochronology and field evidence indicate that strike-slip movement on the Las Vegas Shear Zone was synchronous with igneous activity and normal faulting in both volcanic provinces. These relationships suggest that the Las Vegas Shear Zone may have formed in response to crustal extension in the two volcanic provinces in a manner similar to the formation of a ridge-ridge transform fault, as recognized in ocean floor tectonics.

### Introduction:

Analysis of synoptic imagery from the Earth Resources Technology Satellite (ERTS-1) has guided a regional investigation of tectonic patterns in the Basin Range Province of southern Nevada, eastern California and northwestern Arizona. The area of study is shown in the index map of Figure 1.

A program of literature research and field reconnaissance has been conducted in order to confirm interpretation of the satellite imagery. This synthesis of data has resulted in a tectonic model which relates major strike-slip deformation on the Las Vegas Shear Zone to Basin Range normal faulting, epizonal plutonism, volcanism, and related alteration and mineralization.

Critical parts of this hypothesis were first suggested in an abstract by Fleck (1970), and have since been discussed in greater detail by Anderson and others (1972) and Davis and Burchfiel (1973). The data and concepts presented here draw heavily on the results of studies by other workers in the Basin Range Province. This paper is intended as a synthesis of this work, with the hope of defining problems for further evaluation of the proposed model and its regional genetic implications.

### Regional Geology:

Much of the Great Basin is underlain by a crystalline basement of Precambrian age. Throughout most of the province the basement is mantled by Precambrian, Paleozoic and Mesozoic sediments of the Cordilleran geosyncline, deformed during several orogenies of Paleozoic and Mesozoic age (Armstrong, 1968).

The Mesozoic deformation culminated in late Cretaceous time in a belt of eastward overthrusting and related folding, which extends along the eastern margin of the Great Basin from southeastern California to Idaho. West of the frontal zone of thrusting, the Jurassic and Cretaceous orogenies are expressed by scattered plutonism and associated metamorphism. The Sierra Nevada batholith is thought to represent an Andean type volcanic - plutonic arc of Mesozoic age which formed above a subduction zone near the western continental margin (Burchfiel and Davis, 1972).

Following a 60-million year period of relative stability, formation of the Basin Range Province began in mid-Tertiary time with the onset of block faulting and silicic volcanism. The Basin Range structure is characterized by north trending systems of complex grabens, horsts, and tilted blocks bound by moderately dipping normal faults (Stewart, 1971). The province forms a distinctive physiographic terrane, which can be traced from southern Oregon into northern Mexico.

Systems of both right- and left-lateral strike-slip faults have been recognized within the Basin Range Province, generally striking at high angles to the northerly trend of the ranges. Movement on several of these strike-slip fault systems is known to have been synchronous with Basin Range normal faulting. Examples are the right-lateral Las Vegas Shear Zone and Death Valley-Furnace Creek Fault Zone and the left-lateral Garlock Fault Zone, Pahrnagat Shear System, and Hamblin Bay Fault (Anderson, 1973). The pattern of major Cenozoic faulting in the southern Basin Range Province is shown in Plate 1.

Cenozoic volcanism throughout the Basin Range Province is dominated by voluminous ignimbrites and flows, generally rhyolitic to dacitic in composition. In

many areas erosion has exposed plutonic bodies chemically equivalent to the associated felsic volcanic rocks. This igneous activity was closely related temporally and spatially to Basin Range structural development. The distribution of Cenozoic volcanic and intrusive rocks in the southern Basin Range Province is shown in Plate 2.

Over the last 100 years various theories have been proposed for the origin of Basin Range structure. These theories are discussed in excellent summaries by Nolan (1943), Gilluly (1963), Roberts (1968), and Stewart (1971). Most concepts can be separated into the following three categories:

1. Basin Range structure has resulted from the collapse of the upper crust caused by such mechanisms as lateral transfer of lower crustal material (Gilluly, 1963) or eruption of huge volumes of volcanic magma (Le Conte, 1889; Mackin, 1960).
2. Basin Range structure has formed en echelon to deep seated, conjugate sets of right- and left-lateral strike-slip (Shawe, 1965; Sales, 1966).
3. Basin Range structure is the result of regional crustal extension in a roughly east-west direction (Hamilton and Myers, 1966; Cook, 1966; Roberts, 1968; Stewart, 1971). This process is thought to have occurred through plastic flow of the mantle and lower crust, sometimes accompanied by intrusion of plutons beneath Basin Range grabens (Thompson, 1966). The net amount of crustal extension has been estimated to be as great as 300 km, or approximately 100 percent (Hamilton and Myers, 1966).

Most current theories of Basin Range structure are based on models which presume net crustal extension within the province during late Cenozoic time. Although the amounts, mechanisms and causes of extension in the Basin Range Province remain controversial evidence of extension is well documented by recent geologic mapping and geophysical studies in the province.

#### Tectonic Model:

The tectonic model proposed here was developed in an attempt to synthesize several diverse geologic and structural characteristics of the southern Basin Range Province. We propose that right-lateral strike-slip movement on the Las Vegas Shear Zone may have formed in response to east-west crustal extension in two northerly trending provinces of silicic volcanism, plutonism, and major normal faulting. A generalized structural diagram which illustrates this mechanism is shown in Figure 2.

One area of inferred crustal extension is a volcanic and plutonic province approximately 100 km wide, which is aligned along the Colorado River south of the eastern termination of the Las Vegas Shear Zone. This province is referred to in

this paper as the Black Mountains Volcanic Province. The second area of inferred crustal extension, referred to as the Nye County Volcanic Province, is located north of the western termination of the Las Vegas Shear Zone. The geologic characteristics and chronological development of the Las Vegas Shear Zone and the two volcanic provinces believed to be areas of crustal extension, are summarized below.

#### Las Vegas Shear Zone:

A major zone of right-lateral strike-slip movement passing through Las Vegas Valley (Plate 1) was first postulated by Gianella and Callaghan (1934) in their study of the regional implications of the Cedar Mountain earthquake of 1932. The existence of this fault zone was supported by detailed mapping and named the Las Vegas Valley Shear Zone by Longwell (1960). Although direct evidence of the shear zone is not exposed, indirect evidence cited by several workers, suggests more than 40 km of right-lateral strike-slip. These estimates have been based on displacements of stratigraphic isopachs and sedimentary facies (Longwell and others, 1965; Fleck, 1967; Stewart and others, 1968) and offset of distinctive thrust faults of the Sevier orogenic belt (Longwell and others, 1965; Fleck, 1967).

At the scale of the ERTS-1 MSS imagery, the most impressive evidence for the existence of the shear zone is the flexure in the range trends immediately north and south of the zone. This phenomenon was termed "oroflexure" by Albers (1967). Compensating for the effect of oroflexural drag along the shear zone, Fleck (1967) estimated a total of approximately 70 km of right-lateral strike-slip displacement of features across the deformed belt bordering the shear zone. Of this total displacement, a net slip of 30 km was estimated for features along the trace of the shear zone.

The Las Vegas Shear Zone was mapped by Longwell and others (1965) from near Lake Mead northwestward to the Spector Range, a distance of approximately 120 km. Detailed mapping in the Spector Range by Burchfiel (1965) yielded only indirect evidence of major strike-slip. Burchfiel concluded, however, that deformation within the area was the result of strike-slip movement in the basement, producing rotation and a mosaic of complex faults in the less competent sedimentary cover. Burchfiel did not map a westward continuation of the Las Vegas Shear Zone but suggested possible continuation westward in the form of discontinuous displacements along several faults, including the northwest trending Furnace Creek Fault.

The eastern termination of the Las Vegas Shear Zone is believed to be in the area north of Lake Mead where major right-lateral slip on the shear zone is replaced by a system of faults having apparent left-lateral movement. In this area Anderson (1973) mapped two halves of a Miocene stratovolcano displaced left-laterally a distance of approximately 19 km along a northeast striking fault zone. This structure, which Anderson has named the Hamblin Bay Fault, strikes at a low angle to the easternmost mapped branch of the Las Vegas Shear Zone, which passes north

of Frenchman Mountain (Plate 1).

East of the Hamblin Bay Fault, the Gold Butte and Lime Ridge Faults of Longwell and others (1965) are considered by Anderson (1973) to be possible left-lateral strike-slip faults. Although field evidence is ambiguous, this hypothesis is supported by the flexure of hogback ridges observed adjacent to these faults in ERTS-1 imagery. Sixteen km to the east of the Gold Butte area, Paleozoic and Mesozoic strata of the Colorado Plateau are uplifted on the northerly striking Grand Wash Fault, east of which no evidence of transverse strike-slip faulting is known (see Plate 1).

The duration of movement on the Las Vegas Shear Zone was estimated by Fleck (1967) from radiometric age determinations of rock units along its trace. A radiometric age date of 15 million years from deformed beds of the Gale Hills Formation indicates that major displacement has occurred on the shear zone since that time. Undeformed basalts of the Muddy Creek Formation have been dated at 10.7 million years. From these dates and field evidence Fleck (1967) concluded that most strike-slip movement on the Las Vegas Shear Zone probably occurred during the period from 17 to 10 million years ago.

#### Black Mountains Volcanic Province:

An elongate area extending southward along the Colorado River from Lake Mead, Nevada to near Parker, Arizona is a distinct igneous and structural province, referred to here as the Black Mountains Volcanic Province (see Figure 1 and Plate 2). Reconnaissance maps of portions of this region have been published by Longwell (1963), Longwell and others (1965), Wilson and others (1969), and Volborth (1973). Detailed studies of mining districts within the province have been published by Schrader (1917), Ransome (1923), Callaghan (1939), Anderson (1971), and Thorson (1971).

The Black Mountains Volcanic Province is characterized by thick deposits of ignimbrites, flows and volcanic clastic sediments, generally ranging in composition from andesite to rhyolite. Thin basalt flows are locally widespread in the province. In the area near Nelson, Nevada the composite thickness of the Miocene volcanic sequence is estimated to be over 5 km (Anderson and others, 1972).

The volcanics were deposited on an erosional surface developed on a crystalline basement of Precambrian gneiss and rapakivi granite. In parts of the province, the Precambrian basement may have been subjected to metamorphism during a Jurassic orogeny (Volborth, 1973). Both the pre-Tertiary crystalline basement and the Tertiary volcanics have been intruded by granitic plutons of Miocene age (Anderson and others, 1972; Volborth, 1973). The distribution of these Tertiary volcanic and plutonic units is shown in Plate 2. The plutons are generally elongate north-south, and range in composition from leucocratic granite to gabbro, although granite, quartz monzonite, and quartz diorite predominate (Anderson and others, 1972).

Structurally controlled, northerly striking dikes of rhyolite, andesite and diabase are exposed throughout much of the province, cutting both the crystalline basement and the volcanic cover. In the Newberry Mountains of southern Clark County, Nevada a massive swarm of dikes is especially well exposed forming a belt over 10 km wide. These dikes are bimodal in composition, consisting of porphyritic rhyolite and hornblende diabase. Near Nelson, Nevada dikes of similar compositions are exposed in the lower portions of the volcanic cover, generally decreasing in number upward in the stratigraphic section. It is probable that these dike swarms fed much of the volcanic cover, and were in part synchronous with plutonism (Lausen, 1931; Bechtold and others, 1972; Volborth, 1973).

A close genetic relationship between plutonism and chemically equivalent volcanic facies was suggested as early as 1923 by Ransome in a reconnaissance study of the Oatman mining district, Arizona. This conclusion has been supported by more recent mapping and geochemical studies in this district (Thorson, 1971).

Callaghan (1939) suggested a similar relationship for an intrusive body and adjacent volcanic units in the Searchlight district, Nevada. Through detailed geochemistry and radiometric age date analysis, Volborth (1973) has documented the genetic interrelationship of plutonism, hypabyssal dike emplacement and volcanism over much of the province between Nelson and the Newberry Mountains. Most of the Cenozoic volcanic and hypabyssal intrusive rocks within the province range in age from about 18 to 10 million years before present (Thorson, 1971; Anderson and others, 1972; Volborth, 1973).

Throughout the province the structural deformation is dominated by northerly striking normal faults. In several areas the normal faults dip at angles as low as 10 to 20 degrees, resulting in complex rotation of the volcanic cover. This style of deformation has been mapped in detail near Nelson, Nevada, by Anderson (1971) who attributed the low-angle faulting to extreme east-west distension of the upper crust.

Several normal faults within the Black Mountains Volcanic Province are known to have displacements approaching 2 km (Anderson, 1971; Anderson and others, 1972). Because of the frequency of major normal faults throughout the province, large vertical displacements have occurred between adjacent blocks. Within uplifted blocks, erosion has removed the volcanic cover, and the crystalline basement is commonly juxtaposed against thick sequences of late-Tertiary volcanic rocks.

Although there is insufficient stratigraphic evidence on which to base estimates of net dip-slip on most of the faults in the Black Mountains Volcanic Province, we estimate that crustal extension caused by normal faulting may have exceeded 100 percent. Estimates of similar magnitude have been made in other portions of the Basin Range Province by Hamilton and Myers (1966); Proffett (1971); and Davis and Burchfiel (1973).

Based on a seismic refraction profile across the Las Vegas Shear Zone from near Kingman, Arizona to north of the Las Vegas Shear Zone, Roller (1964) has suggested that an anomalously thin crust of 27 km underlies the Black Mountains Volcanic Province. Just north of the Las Vegas Shear Zone, the crust increases to a more normal thickness of 32 km. This pattern is supported by the existence of a northerly trending Bouguer gravity high (USAF, 1968) which is aligned with the Black Mountains Volcanic Province, suggesting an upward bulge of the mantle beneath this area. This mantle bulge may be the result of isostatic compensation for thin, distended crust in the Black Mountains Volcanic Province. The high gravity anomaly, like the volcanic province, terminates north of Lake Mead along the Las Vegas Shear Zone and the Hamblin Bay Fault.

The southern end of the Black Mountains Volcanic Province is complex and indefinite. The pattern of volcanism, plutonism and normal faulting appears to terminate in the vicinity of Parker, Arizona, against a broad zone of southeast striking faults. Although this fault system is poorly mapped, field reconnaissance along portions of the system near Vicksburg, Arizona has revealed abundant slickensides having moderate plunges, suggesting probable components of strike-slip displacement. The amount and sense of displacement along the entire zone are unknown.

#### Nye County Volcanic Province:

A sister area of Miocene volcanism, plutonism and extensional normal faulting lies northwest of the Las Vegas Shear Zone in southern Nye County, Nevada. This area is referred to here as the Nye County Volcanic Province (see Figure 1 and Plate 2). This province is a northerly trending area of ten known volcanic centers, at least five of which are believed to be caldera collapse structures (Ekren, 1968). Within the province detailed geologic studies have been conducted in several mining areas associated with Tertiary volcanism at Rhyolite, Beatty (Cornwall and Kleinhampl, 1964), and Goldfield, Nevada (Ransome, 1909; Cornwall, 1972). Detailed mapping, stratigraphic and geophysical studies were conducted by the U. S. Geological Survey in the area of the Atomic Energy Commission's Southern Nevada Test Site (see Eckel, 1968).

The Tertiary ignimbrites and volcanic flows recognized within the Nye County Volcanic Province are estimated to have a composite thickness of approximately 9 km, and a volume estimated to be over 11,000 km<sup>3</sup> (Ekren, 1968). Most of these rocks range in composition from dacite to rhyolite, although andesite and basalt flows are locally abundant (Anderson and Ekren, 1968; Ekren, 1968). The volcanic units uncomformably overlie a basement of Paleozoic carbonate rocks, which were folded, thrust faulted and metamorphosed during Mesozoic time. Several Mesozoic plutons have intruded this Paleozoic basement.

Numerous small plugs, domes and dikes ranging in composition from rhyolite to andesite with minor basalt have intruded the Tertiary volcanic cover. These in-

trusives are similar in composition to the volcanics and are believed to be feeders (Ekren and others, 1971). Larger Tertiary plutons may exist beneath the volcanic cover, but have not been exposed by erosion. Most of the volcanism and plutonism within the province was synchronous with Basin Range normal faulting in a time span from approximately 26.5 to 11 million years ago (Ekren and others, 1968).

Tertiary structural deformation within the Nye County Volcanic Province is dominated by northerly striking normal faults and by caldera subsidence, doming and radial faulting related to the volcanic centers. Known displacements on individual faults which form the complex horst and graben structure of the province exceed 900 meters (Cornwall, 1972). Arcuate faults that rim subsident structures have displacements estimated on the basis of gravity anomalies and drill data to be as great as 2,000 meters (Orkild and others, 1968). However, much of the Basin Range structure is masked by the youngest volcanic rocks, and the full extent of normal faulting is unknown. On the basis of gravity data, several basins are estimated to be filled with as much as 4.8 km of volcanic rock (Healey, 1968). Structural control of these basins is suggested by the strong north trending grain of the gravity anomaly patterns.

The Nye County Volcanic Province terminates southward against the northwestern end of the Las Vegas Shear Zone. This complex structural intersection involves a westward flexure of the ranges immediately north of the Las Vegas Shear Zone, and includes several short northeast striking faults believed to have undergone left-lateral strike-slip movement of between 3 and 5 km (Ekren, 1968). This complex pattern of deformation is similar to that of the eastern end of the Las Vegas Shear Zone north of Lake Mead, Nevada. No definite continuation of the Las Vegas Shear Zone has been recognized west of the Nye County Volcanic Province.

#### Discussion:

##### Chronology:

The structural model proposed here for the late Tertiary deformation in the southern Basin Range Province is supported by the synchronism of strike-slip movement on the Las Vegas Shear Zone and volcanism, plutonism, and normal faulting in the two areas of inferred crustal extension.

The folding and thrust faulting of the Sevier orogeny within the southern Basin Range Province is believed to have been confined to a relatively brief time span of from 90 to 75 million years ago (Fleck, 1970b). This orogenic episode is reflected in several deposits of Cretaceous continental clastic sediments in the area north and west of Lake Mead (Longwell and others, 1965). The Sevier orogeny appears to have been followed by a long period of relative stability and moderate erosion which resulted in a broad terrane of subdued topography.

During mid-Tertiary time the area south of Lake Mead appears to have formed a broad arch, which shed arkosic conglomerates and fanglomerates containing fragments of Precambrian rock toward the northeast. These sediments overlie an erosional surface cut in the Paleozoic rock of the western Colorado Plateau northeast of Kingman, Arizona. The sediments are conformably overlain by the Peach Springs Tuff variously dated at  $18.3 \pm 0.6$  million years (Lucchitta, 1972) and  $16.9 \pm 0.4$  million years (Young and Brennan, 1974). These relationships indicate that by Miocene time, erosion had unroofed Precambrian basement in the arch south of Lake Mead, and that major normal faulting had not yet occurred to separate depositional areas on the Colorado Plateau from source areas in the ancestral Basin Range Province (Lucchitta, 1972). Following deposition of the Peach Springs Tuff, Basin Range faulting disrupted the northeast flowing drainage, leading to formation of a new pattern of isolated structural depressions filled by basin deposits (Lucchitta, 1972).

In the Black Mountains Volcanic Province the oldest volcanic rocks overlying the Precambrian crystalline basement are tuff units from the Patsy Mine volcanics believed to be 18.6 million years old (Anderson and others, 1972). Dates from the upper Patsy Mine volcanics indicate an age of about 14.5 million years. This range in dates suggests that 13,000 feet of volcanic rock were erupted over a period of approximately 4 million years. The youngest volcanic units of volumetric significance in the area consist of tuffs and flows dated at 12.7 million years (Anderson and others, 1972). Most of the epizonal plutonic rocks in the Black Mountains Volcanic Province range in age from 18 to 10 million years.

In the area of the Nye County Volcanic Province, the chronology of volcanism and structural deformation is similar. A subdued erosional surface developed on the folded and thrust faulted Paleozoic basement in early Tertiary time. This surface was overlain by a widespread welded tuff dated at 26.5 million years (Ekren and others, 1968). Normal faults striking toward the northeast and northwest developed shortly after the eruption of this tuff unit. Typical north trending Basin Range faults first began to form in the area sometime after deposition of a tuff breccia dated at 17.8 million years, and continued to form synchronously with the eruption of subsequent volcanic units. Much of the normal faulting followed eruption of the Timber Mountain caldera 11 million years ago; however, the present mountain ranges are believed to have been well defined prior to extrusion of the Thirsty Canyon Tuff dated at 7 million years (Ekren and others, 1968).

In summary, the first Tertiary volcanism and Basin Range normal faulting began in the Black Mountains and Nye County Volcanic Provinces approximately 20 million years ago. Strike-slip deformation on the Las Vegas Shear Zone appears to have begun about 17 million years ago and to have continued synchronously with igneous activity and extensional normal faulting in

both provinces. Major strike-slip movement, and silicic volcanism and plutonism ended by approximately 10 million years ago.

#### Mineralization:

Gold, silver, and minor copper mineralization within the Black Mountains and Nye County Volcanic Provinces is believed to be genetically related to the unique igneous and structural settings of these areas of inferred crustal extension.

Within the Black Mountains Volcanic Province major gold and silver deposits have been mined in the Eldorado and Searchlight districts in Clark County, Nevada, and in the Catherine and Oatman districts east of the Colorado River in Arizona. Small mine workings and prospects for gold, silver and copper are found throughout the province. The known ore deposits are spatially associated with the silicic intrusive bodies of Miocene age that have intruded the Precambrian basement and volcanic cover within the province (Bechtold and others, 1973). The ore bodies typically occur as veins having quartz, calcite and adularia gangue; disseminated sulphide mineralization is generally rare. The mineralized veins are localized along the northerly striking normal faults which dominate the structure of the province, and along transverse faults, some of which are known to have had strike-slip movement. Several of the richer districts appear to be located in areas where this transverse structural trend is well developed (see Volborth, 1973). Formation of the mineralized veins postdated the bulk of volcanism and plutonism in the Black Mountains Volcanic Province, but probably occurred synchronously with late normal faulting and dike intrusion. Mineralized veins frequently show several generations of fracturing and deposition of quartz and calcite (see Ransome, 1923, p. 35).

In the Nye County Volcanic Province gold, silver and minor copper deposits have been mined in many areas, including the Goldfield, Tonopah and Bullfrog districts. These districts are spatially associated with Tertiary volcanic centers and are similar to the deposits of the Black Mountains Volcanic Province in ore and gangue mineralogy, and structural settings. The veins are generally aligned along northerly striking normal faults or fracture zones within the Tertiary intrusive rocks and volcanics. In the Bullfrog district most of the known mineralized veins are along normal faults that are believed to be boundary faults for the Bullfrog Hills caldera (Cornwall and Kleinhampl, 1964).

The distributions and ages of known mineralization within parts of the Nye County Volcanic Province have been summarized by Albers and Kleinhampl (1970). The mineralization in different parts of the province is believed to have followed the bulk of local volcanism and plutonism. Mineralization in the Bullfrog district is thought to be less than 11 million years old; mineralization at Goldfield is believed to have occurred approximately 21 million years

ago and at Tonopah, between 22 and 17.5 million years ago.

### Conclusions:

The diagrammatic structural model illustrated in Figure 2 unifies many of the temporal and spatial relationships between strike-slip movement on the Las Vegas Shear Zone and normal faulting, volcanism, plutonism, and mineralization in the Black Mountains and Nye County Volcanic Provinces. The Las Vegas Shear Zone is believed to have functioned as a transform fault, separating two areas of simultaneous crustal extension and formation of new crust by volcanism and plutonism.

As shown in Figure 2, the Las Vegas Shear Zone is mechanically similar to a ridge-ridge transform fault described by Wilson (1965, p. 343) as a type of fault for which ".... the horizontal shear motion along the fault ends abruptly by being changed into an expanding tensional motion across the ridge or rift with a [corresponding] change of seismicity." Wilson (1965, p. 343) describes transform faults as ".... a separate class of horizontal shear faults .... which terminate abruptly at both ends, but which nevertheless may show great displacements." Wilson's distinction between transform faults and other strike-slip faults has been challenged by Garfunkel (1972, p. 3491), who argues that ".... all [strike-slip faults] must terminate on structures in which surface area is increased or decrease decreased. This is a direct consequence of the occurrence of strike-slips on these faults." Garfunkel considers ridge-ridge transform faults to be a type of strike-slip fault that cuts and displaces oceanic crust formed in part synchronously with fault movement. We believe that the Las Vegas Shear Zone is a continental analogue of such a structure.

In a less restricted use of the term, the concept of intracontinental transform faulting has been proposed for other structures in the southern Basin Range Province. The left-lateral displacement on the Garlock Fault Zone of eastern California is believed to be the result of westward crustal extension on Basin Range normal faults north of the fault zone (Hamilton and Myers, 1966; Elders and others, 1970; Davis and Burchfiel, 1973). Left-lateral displacement on the Pahrnagat Shear System in southern Lincoln County, Nevada is postulated to have resulted from differential amounts of extension on Basin Range normal faults northeast and southwest of the shear system (Liggett and Ehrenspeck, 1974).

The tectonic model proposed here for the Las Vegas Shear Zone is largely mechanical, and does not explain the driving mechanisms for crustal extension or the physicochemical controls of magma genesis and mineralization in the areas of inferred crustal extension. It is hoped that this model will provide a basis for future investigations of these intriguing problems.

This investigation has benefited greatly from the detailed work of many other geologists in the southern Basin Range Province. In addition, the synthesis of data presented here was facilitated by analysis and interpretation of synoptic

imagery from the ERTS-1 satellite. The ERTS-1 imagery has provided an effective tool for the study of regional tectonic patterns and for guiding research to confirm interpretation.

Acknowledgements:

We wish to thank H. E. Ehrenspeck for his aid in preparation of the map compilations of Plates 1 and 2, and A. K. Baird for his constructive criticism and suggestions.

This investigation was supported by the National Aeronautics and Space Administration and Cyprus Mines Corporation as part of a program investigating the use of ERTS-1 MSS imagery for the study of regional tectonics and related resource exploration.

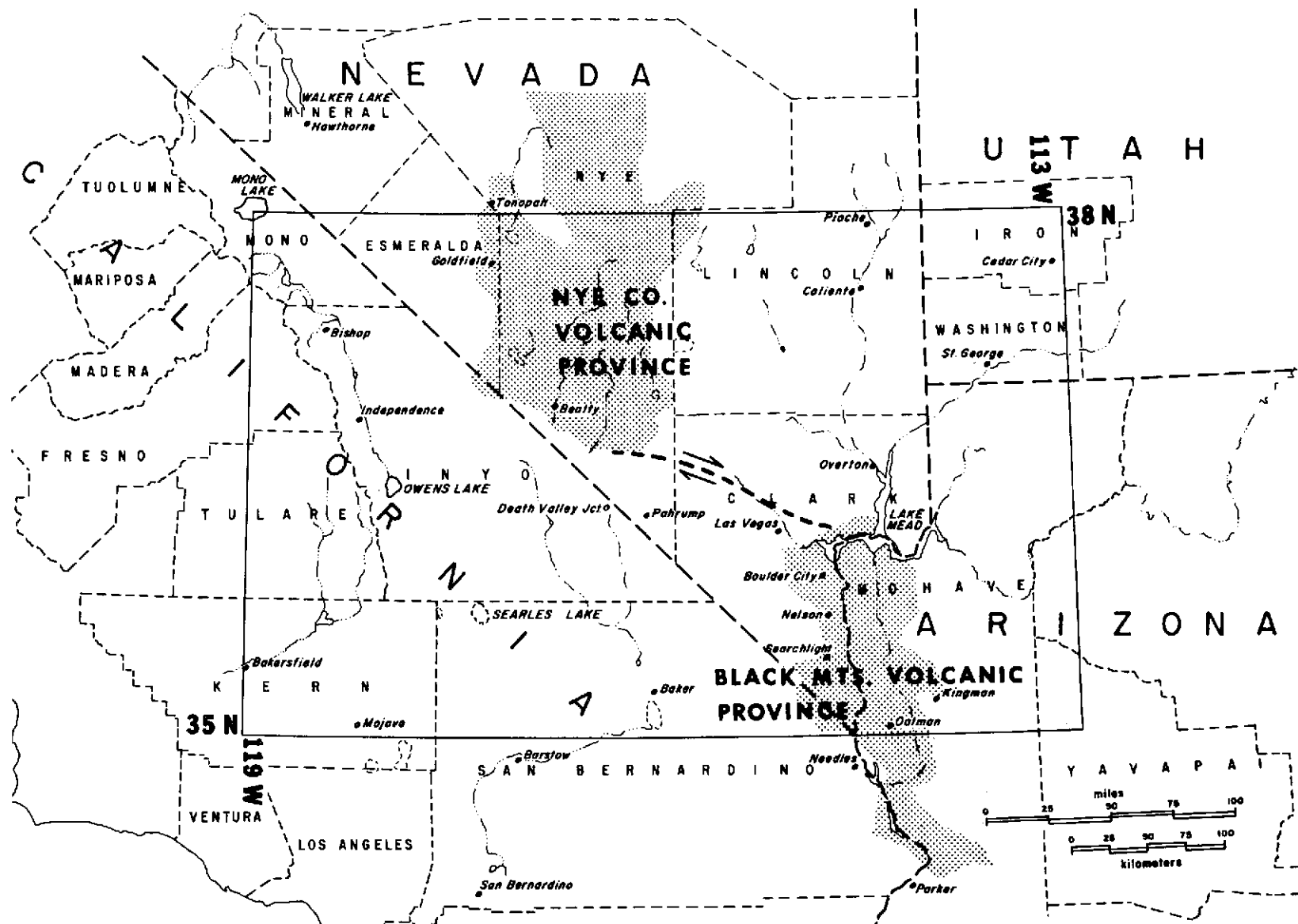


Figure 1: Location map for the area of study. The generalized positions of the Nye County and Black Mountains Volcanic Provinces are indicated with the stippled pattern. The trace of the Las Vegas Shear Zone is shown between these two areas.

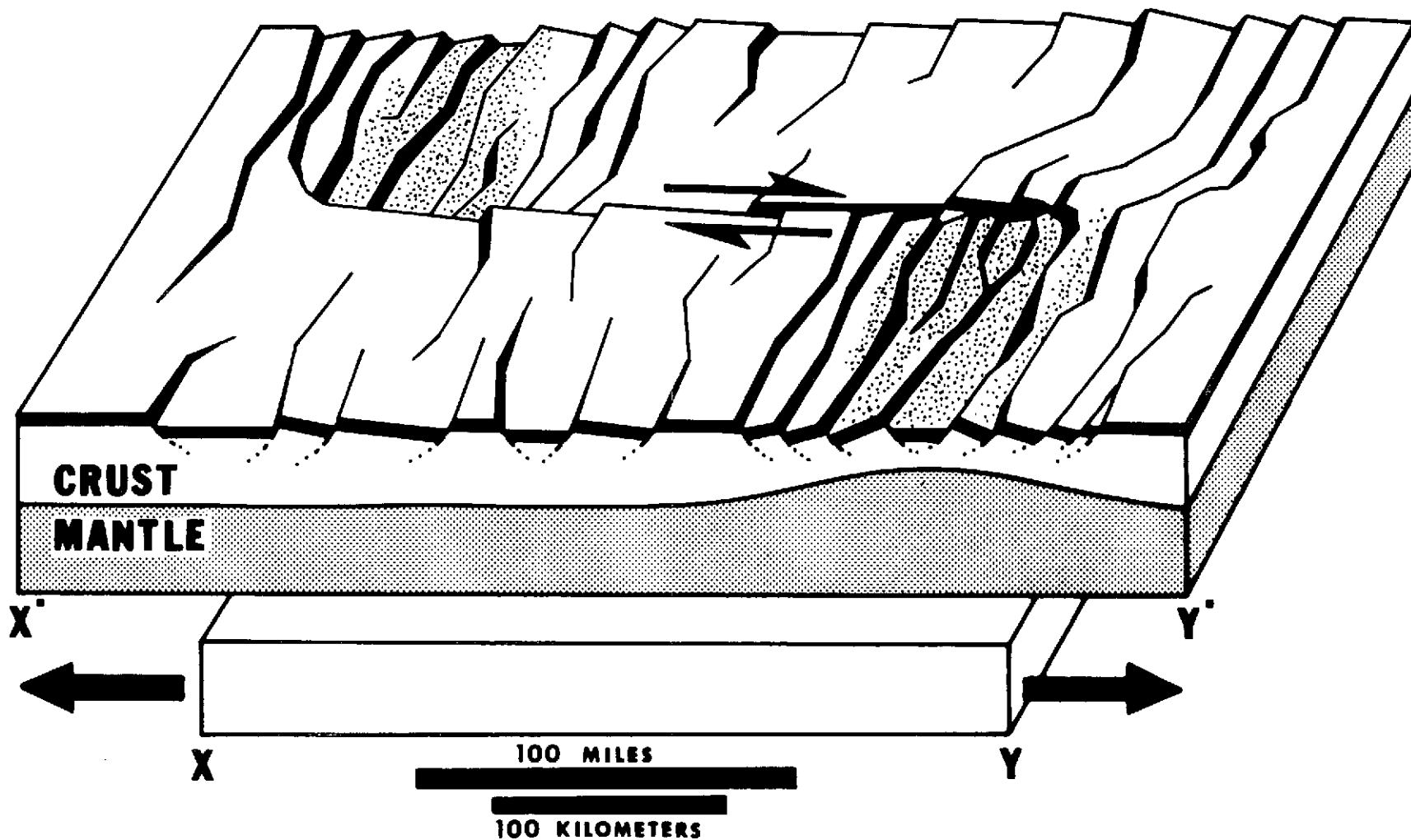


Figure 2: Diagrammatic model of the Las Vegas Shear Zone, separating two areas of crustal extension. Right-lateral strike-slip movement on the Las Vegas Shear Zone is believed to have occurred in response to extension by dip-slip faulting, and formation of new crust by plutonism and volcanism (stippled pattern). The upward bulge of the mantle is believed to be the result of isostatic compensation for the thin, distended crust. The amount of extension is represented by the increase in length of  $X - Y$  to  $X' - Y'$ .

#### References Cited in Text:

- Albers, J. P., 1967, Belt of sigmoidal bending and right-lateral faulting in the western Great Basin: *Geol. Soc. America Bull.*, v. 78, p. 143-156.
- Albers, J. P., and Kleinhampl, F. J., 1970, Spatial relation of mineral deposits to Tertiary volcanic centers in Nevada: *U.S. Geol. Survey Prof. Paper 700-C*, p. C1-C10.
- Anderson, R. E., and Ekren, E. B., 1968, Widespread Miocene igneous rocks of intermediate composition, southern Nye County, Nevada: *in* Eckel, E. B., ed., *Nevada Test Site: Geol. Soc. America Memoir 110*, p. 57-63.
- Anderson, R. E., 1971, Thin skin distension in Tertiary rocks of southeastern Nevada: *Geol. Soc. America Bull.*, v. 82, p. 43-58.
- Anderson, R. E., Longwell, C. R., Armstrong, R. L., and Marvin, R. F., 1972, Significance of K-Ar ages of Tertiary rocks from the Lake Mead region, Nevada-Arizona: *Geol. Soc. America Bull.*, v. 83, p. 273-288.
- Anderson, R. E., 1973, Large-magnitude late Tertiary strike-slip faulting north of Lake Mead, Nevada: *U.S. Geol. Survey Prof. Paper 794*, 18 p.
- Armstrong, R. L., 1968, Sevier orogenic belt in Nevada and Utah: *Geol. Soc. America Bull.*, v. 79, p. 429-458.
- Bechtold, I. C., Liggett, M. A., and Childs, J. F., November 1972, Structurally controlled dike swarms along the Colorado River, northwestern Arizona and southern Nevada (abs): *NASA Rept. Inv.*, NASA-CR-128390, E72-10192, 2 p.
- Bechtold, I. C., Liggett, M. A., and Childs, J. F., March 1973, Regional tectonic control of Tertiary mineralization and recent faulting in the southern Basin-Range Province, an application of ERTS-1 data: *Symposium on significant results obtained from the Earth Resources Technology Satellite-1*, New Carrollton, Maryland, v. 1, sect. A, NASA-SP-327, E73-10824, p. 425-432.
- Burchfiel, B. C., 1965, Structural geology of the Specter Range quadrangle, Nevada, and its regional significance: *Geol. Soc. America Bull.*, v. 76, p. 175-192.

- Burchfiel, B.C., and Davis, G.A., 1972, Structural framework and evolution of the southern part of the Cordilleran orogen, western United States: Am. Jour. Sci., v. 272, p. 97-118.
- Callaghan, E., 1939, Geology of the Searchlight district, Clark County, Nevada: U.S. Geol. Survey Bull. 906 D, p. 135-185.
- Cook, K.L., 1966, Rift system in the Basin and Range province, in The world rift system: Canada Geol. Survey Paper 66-14, p. 246-279.
- Cornwall, H.R., and Kleinhampl, F.J., 1964, Geology of Bullfrog quadrangle and ore deposits related to Bullfrog Hills caldera, Nye County, Nevada and Inyo County, California: U.S. Geol. Survey Prof. Paper 454-J, 25 p.
- Cornwall, H.R., 1972, Geology and mineral deposits of southern Nye County, Nevada: Nevada Bur. Mines and Geology Bull. 77, 49 p.
- Davis, G.A., and Burchfiel, B.C., 1973, Garlock fault: An intracontinental transform structure, southern California: Geol. Soc. America Bull., v. 84, p. 1407-1422.
- Eckel, E.B., ed., 1968, Nevada Test Site: Geol. Soc. America Memoir 110, 290 p.
- Ekren, E.B., 1968, Geologic setting of the Nevada Test Site and Nellis Air Force Range: in Eckel, E.B., ed., Nevada Test Site: Geol. Soc. America Memoir 110, p. 11-20.
- Ekren, E.B., Rogers, C.L., Anderson, R.E., and Orkild, P.P., 1968, Age of Basin and Range normal faults in Nevada Test Site and Nellis Air Force Range, Nevada: in Eckel, E.B., ed., Nevada Test Site: Geol. Soc. America Memoir 110, p. 247-250.
- Ekren, E.B., Anderson, R.E., Rogers, C.L., and Noble, D.C., 1971, Geology of northern Nellis Air Force Base Bombing and Gunnery Range, Nye County, Nevada: U.S. Geol. Survey. Prof. Paper 651, 91 p.
- Elders, W.A., Rex, R.W., Meidav, T., Robinson, P.T., 1970, Crustal spreading in southern California, The Imperial Valley of California is a product of oceanic spreading centers acting on a continental plate: Institute Geophysics and Planetary Physics, Riverside, Univ. California, 11 p.

- Fleck, R.J., 1967, The magnitude, sequence, and style of deformation in southern Nevada and eastern California (Ph.D. thesis): Berkeley, Univ. California, 92 p.
- Fleck, R.J., 1970a, Age and possible origin of the Las Vegas shear zone, Clark and Nye Counties, Nevada: Geol. Soc. America, Abs. with Programs (Rocky Mtn. sect.), v. 2, no. 5, p. 333.
- Fleck, R.J., 1970b, Tectonic style, magnitude, and age of deformation in the Sevier orogenic belt in southern Nevada and eastern California: Geol. Soc. America Bull., v. 81, p. 1705-1720.
- Garfunkel, Z., 1972, Transcurrent and transform faults: A problem of terminology: Geol. Soc. America Bull., v. 83, p. 3491-3496.
- Gianella, V.P., and Callaghan, E., 1934, The earthquake of December 20, 1932, at Cedar Mountain, Nevada and its bearing on the genesis of Basin Range structure: Jour. Geology, v. 42, no. 1, p. 1-22.
- Gilluly, J., 1963, The tectonic evolution of the western United States: Geol. Soc. London Quart. Jour., v. 119, p. 133-174.
- Hamilton, W., and Myers, W.B., 1966, Cenozoic tectonics of the western United States: Rev. Geophysics, v. 4, no. 4, p. 509-549.
- Healey, D.L., 1968, Application of gravity data to geologic problems at Nevada Test Site: in Eckel, E.B., ed., Nevada Test Site: Geol. Soc. America Memoir 110, p. 147-156.
- Lausen, Carl., 1931, Geology and ore deposits of the Oatman and Katherine districts, Arizona: Arizona Bur. Mines and Geol. Series no. 6, Bull. 131, 126 p.
- Le Conte, J., 1889, On the origin of normal faults and of the structure of the Basin region: Am. Jour. Sci., Third series, v. 38, no. 226, p. 257-263.
- Liggett, M.A., and Ehrenspeck, H.E., January 1974, Pahrnagat shear system, Lincoln County, Nevada: NASA Rept. Inv., 10 p.
- Longwell, C. R., 1960, Possible explanation of diverse structural patterns in southern Nevada: Am. Jour. Sci. (Bradley Volume), v. 258-A, p. 192-203.

- Longwell, C.R., 1963, Reconnaissance geology between Lake Mead and Davis Dam, Arizona-Nevada: U.S. Geol. Survey Prof. Paper 374-E, p. E1-E51.
- Longwell, C.R., Pampeyan, E.H., Bowyer, B., and Roberts, R.J., 1965, Geology and mineral deposits of Clark County, Nevada: Nevada Bur. Mines and Geology Bull. 62, 218 p.
- Lucchitta, I., 1972, Early history of the Colorado River in the Basin and Range province: Geol. Soc. America Bull., v. 83, p. 1933-1948.
- Mackin, J.H., 1960, Structural significance of Tertiary volcanic rocks in southwestern Utah Am. Jour. Sci., v. 258, p. 81-131.
- Nolan, T.B., 1943, The Basin and Range province in Utah, Nevada and California: U.S. Geol. Survey Prof. Paper 197-D, p. 141-196.
- Orkild, P.P., Byers, F.M., Jr., Hoover, D.L., and Sargent, K.A., 1968, Subsurface geology of Silent Canyon caldera, Nevada Test Site, Nevada: in Eckel, E.B., ed., Nevada Test Site: Geol. Soc. America Memoir 110, p. 77-86.
- Proffett, J.M., Jr., 1971, Late Cenozoic structure in the Yerington district, Nevada and the origin of the Great Basin: Geol. Soc. America, Abs. with Programs (Cordilleran sect.), v. 3, no. 2, p. 181.
- Ransome, F.L., 1909, The geology and ore deposits of Goldfield, Nevada: U.S. Geol. Survey Prof. Paper 66, 258 p.
- Ransome, F.L., 1923, Geology of the Oatman gold district, Arizona; A preliminary report: U.S. Geol. Survey Bull. 743, 58 p.
- Roberts, R.J., 1968, Tectonic framework of the Great Basin: Rolla, Univ. Missouri Res. Jour., no. 1, p. 101-119.
- Roller, J.C., 1964, Crustal structure in the vicinity of Las Vegas, Nevada, from seismic and gravity observations: U.S. Geol. Survey Prof. Paper 475-D, p. D108-D111.
- Sales, J.K., 1966, Structural analysis of the Basin Range province in terms of wrench faulting (Ph.D. dissert.): Reno, Univ. Nevada, 289 p.
- Schrader, F.C., 1917, Geology and ore deposits of Mohave County, Arizona: Trans. Amer. Inst. Min. Engineers, v. 56, p. 195-236.

- Shawe, D.R., 1965, Strike-slip control of Basin-Range structure indicated by historical faults in western Nevada: *Geol. Soc. America Bull.*, v. 76, p. 1361-1378.
- Stewart, J.H., Albers, J.P., and Poole, F.G., 1968, Summary of regional evidence for right-lateral displacement in the western Great Basin: *Geol. Soc. America Bull.*, v. 79, p. 1407-1414.
- Stewart, J.H., 1971, Basin and Range structure: A system of horsts and grabens produced by deep-seated extension: *Geol. Soc. America Bull.*, v. 82, p. 1019-1044.
- Thompson, G.A., 1960, Problem of late Cenozoic structure of the Basin Ranges: *International Geol. Congress*, session 21, part 18, p. 62-68.
- Thompson, G.A., 1966, The rift system of the western United States, *in* *The world rift system*: Canada Geol. Survey Paper 66-14, p. 280-290.
- Thorson, J.P., 1971, Igneous petrology of the Oatman district, Mohave County, Arizona (Ph.D. dissert.): Santa Barbara, Univ. California, 173 p.
- U.S. Air Force Aeronautical Chart and Information Center, 1968, Transcontinental Geophysical Survey (35°-39°N) Bouguer gravity map from 112° W. Longitude to the coast of California: U.S. Geol. Survey, Misc. Geologic Inv. Map I-532-B.
- Volborth, Alexis, 1973, Geology of the granite complex of the Eldorado, Newberry and northern Dead Mountains, Clark County, Nevada: *Nevada Bur. Mines and Geology Bull.* 80, 40 p.
- Wilson, E.D., Moore, R.T., and Cooper, T.R., 1969, Geologic map of Arizona: U.S. Geol. Survey, scale 1:500,000.
- Wilson, J.T., 1965, A new class of faults and their bearing on continental drift: *Nature*, v. 207, p. 343-347.
- Young, R.A., and Brenman, W.J., 1974, Peach Springs Tuff: Its bearing on structural evolution of the Colorado Plateau and development of Cenozoic drainage in Mohave County, Arizona: *Geol. Soc. America Bull.*, v. 85, p. 83-90.

References Used in Compiling Plate 1:

- Albers, J. P., and Stewart, J. H., 1972, Geology and mineral deposits of Esmeralda County, Nevada: Nevada Bur. Mines and Geology Bull. 78, 80 p.
- Anderson, R. E., 1971, Thin skin distension in Tertiary rocks of southeastern Nevada: Geol. Soc. America Bull., v. 82, p. 43-58.
- Anderson, R. E., 1973, Large-magnitude late Tertiary strike-slip faulting north of Lake Mead, Nevada: U.S. Geol. Survey Prof. Paper 794, 18 p.
- Bassett, A. M., and Kupfer, D. H., 1964, A geologic reconnaissance in the southeastern Mojave Desert, California: California Div. Mines and Geol., Spec. Rept. 83, 43 p.
- Bateman, P. C., 1965, Geologic map of the Blackcap Mountain quadrangle, Fresno County, California: U.S. Geol. Survey Map GQ-428, scale 1:62,500.
- Bateman, P. C., and Moore, J. G., 1965, Geologic map of the Mount Goddard quadrangle, Fresno and Inyo Counties, California: U.S. Geol. Survey Map GQ-429, scale 1:62,500.
- Bechtold, I. C., Liggett, M. A., Childs, J. F., March 1973, Regional tectonic control of Tertiary mineralization and Recent faulting in the southern Basin-Range Province: An application of ERTS-1 data: in Freden, S. C., Mercanti, E. P., and Becker, M. A., eds., Symposium on significant results obtained from ERTS-1, New Carrollton, Maryland, v. 1, sect. A, paper G-21, NASA-SP-327, E73-10824, p. 425-432.
- Bishop, C. C., 1963, Geologic map of California, Needles sheet, Olaf P. Jenkins edition: California Div. Mines and Geology, scale 1:250,000.
- Bowen, O. E., Jr., 1954, Geology and mineral deposits of Barstow quadrangle, San Bernardino County, California: California Div. Mines and Geology Bull. 165, 208 p.
- Callaghan, Eugene, 1939, Geology of the Searchlight district, Clark County, Nevada: U.S. Geol. Survey Bull. 906-D, p. 135-185.
- Childs, J. F., July 1973, The Salt Creek Fault, Death Valley, California (abs.): NASA Rept. Inv., NASA-CR-133141, E73-10774, 6 p.
- Childs, J. F., November 1973, A major normal fault in Esmeralda County, Nevada (abs.): NASA Rept. Inv., 6 p.

- Childs, J. F., January 1974, Fault pattern at the northern end of the Death Valley-Furnace Creek Fault Zone, California and Nevada: NASA Rept. Inv., 8 p.
- Clary, M. R., 1967, Geology of the eastern part of the Clark Mountains Range, San Bernardino County, California: California Div. Mines and Geology Map Sheet 6.
- Cook, E. F., 1957, Geology of the Pine Valley Mountains, Utah: Utah Geol. and Mineralog. Survey Bull. 58, 111 p.
- Cook, E. F., 1960, Geologic atlas of Utah, Washington County: Utah Geol. and Mineralog. Survey Bull. 70, 124 p.
- Cornwall, H. R., 1972, Geology and mineral deposits of southern Nye County, Nevada: Nevada Bur. Mines and Geology Bull. 77, 49 p.
- Crowder, D. F., Robinson, P. F., and Harris, D. L., 1972, Geologic map of the Benton quadrangle, Mono County, California and Esmeralda and Mineral Counties, Nevada: U.S. Geol. Survey Map GQ-1013, scale 1:62,500.
- Ekren, E. B., Anderson, R. E., Rogers, C. L., and Noble, D. C., 1971, Geology of northern Nellis Air Force Base Bombing and Gunnery Range, Nye County, Nevada: U.S. Geol. Survey Prof. Paper 651, 91 p.
- Gilbert, C. M., Christensen, M. N., Al-Rawi, Y., and Lajoie, K. L., 1968, Structural and volcanic history of Mono Basin, California-Nevada, in Coats, R. R., Hay, R. L., and Anderson, C. A., eds., Studies in volcanology: Geol. Soc. America Memoir 116, p. 275-329.
- Gillespie, J. B., and Bentley, C. B., 1971, Geohydrology of Hualapai and Sacramento Valleys, Mohave County, Arizona: U.S. Geol. Survey Water-Supply Paper 1899-H, p. H1-H37.
- Goodwin, J. G., 1958, Mines and mineral resources of Tulare County, California: California Jour. Mines and Geology, v. 54, no. 3, p. 317-492.
- Gregory, H. E., 1950, Geology of eastern Iron County, Utah: Utah Geol. and Mineralog. Survey Bull. 37, 153 p.
- Hall, W. E., and Mackevett, E. M., 1958, Economic geology of the Darwin quadrangle, Inyo County, California: California Div. Mines and Geology Spec. Rept. 51, 73 p.

- Hall, W.E., and Stephens, H.G., 1963, Economic geology of the Panamint Butte quadrangle and Modoc district, Inyo County, California: California Div. Mines and Geology, Spec. Rept. 73, 39 p.
- Hamblin, W.K., 1970, Structure of the western Grand Canyon region, in Hamblin, W.K., and Best, M.G., eds., Guidebook to the geology of Utah: Utah Geol. Soc. no. 23, p. 3-20.
- Hansen, S.M., 1962, The geology of the Eldorado mining district, Clark County, Nevada (Ph.D. thesis): Rolla, Univ. Missouri, 262 p.
- Hewett, D.F., 1931, Geology and ore deposits of the Goodsprings quadrangle, Nevada: U.S. Geol. Survey Prof. Paper 162, 172 p.
- Heylman, E.B., ed., 1963, Guidebook to the geology of southwestern Utah: Intermountain Assoc. Petroleum Geologists, 12th Annual Field Conference, Salt Lake City, Utah, 232 p.
- Hintze, L.F., 1963, Geologic map of southwestern Utah: Utah Geol. and Mineralog. Survey, scale 1:250,000.
- Huber, N.K., and Rinehart, C.D., 1965, Geologic map of the Devils Postpile quadrangle, Sierra Nevada, California: U.S. Geol. Survey Map GQ-437, scale 1:62,500.
- Jahns, R.H., ed., 1954, Geology of southern California: California Div. Mines and Geology Bull. 170.
- Jennings, C.W., 1958, Geologic map of California, Death Valley sheet, Olaf P. Jenkins edition: California Div. Mines and Geology, scale 1:250,000.
- Jennings, C.W., 1961, Geologic map of California, Kingman sheet, Olaf P. Jenkins edition: California Div. Mines and Geology, scale 1:250,000.
- Jennings, C.W., 1972, Geologic map of California, south half (preliminary): California Div. Mines and Geology, scale 1:750,000.
- Jennings, C.W., Burnett, J.L., and Troxel, B.W., 1962, Geologic map of California, Trona sheet, Olaf P. Jenkins edition: California Div. Mines and Geology, scale 1:250,000.
- Jennings, C.W., and Strand, R.G., 1969, Geologic map of California, Los Angeles sheet, Olaf P. Jenkins edition: California Div. Mines and Geology, scale 1:250,000.

- Koenig, J.B., 1963, Geologic map of California, Walker Lake sheet, Olaf P. Jenkins edition: California Div. Mines and Geology, scale 1:250,000.
- Krauskopf, K.B., 1971, Geologic map of the Mt. Barcroft quadrangle, California-Nevada: U.S. Geol. Survey Map GQ-960, scale 1:62,500.
- Kupfer, D.H., 1960, Thrust faulting and chaos structure, Silurian Hills, San Bernardino County, California: Geol. Soc. America Bull., v. 71, p. 181-214.
- Liggett, M.A., and Childs, J.F., July 1973, Evidence of a major fault zone along the California-Nevada state line 35°30'-36°30' N. latitude. An application of ERTS-1 satellite imagery: NASA Rept. Inv., 10 p.
- Liggett, M.A., and Childs, J.F., February 1974, Structural lineaments in the southern Sierra Nevada, California: NASA Rept. of Inv., 9 p.
- Liggett, M.A., and Ehrenspeck, H.E., January 1974, Pahrnagat Shear System, Lincoln County, Nevada: NASA Rept. Inv., 10 p.
- Longwell, C.R., Pampeyan, E.H., Bowyer, B., and Roberts, R.J., 1965, Geology and mineral deposits of Clark County, Nevada: Nevada Bur. Mines and Geology Bull. 62, 218 p.
- Malmberg, G.T., 1967, Hydrology of the valley-fill and carbonate-rock reservoirs, Pahrump Valley, Nevada-California: U.S. Geol. Survey Water Supply Paper 1832, 47 p.
- Matthews, R.A., and Burnett, J.L., 1965, Geologic map of California, Fresno sheet, Olaf. P. Jenkins edition: California Div. Mines and Geology, scale 1:250,000.
- Maxey, G.B., and Jameson, C.H., 1948, Geology and water resources of Las Vegas, Pahrump, and Indian Spring Valleys, Clark and Nye Counties, Nevada: Nevada Water Resources Bull. 5, 121 p.
- McAllister, J.F., 1952, Rocks and structure of the Quartz Spring area, northern Panamint Range, California: California Div. Mines and Geology Spec. Rept. 25, 38 p.
- McAllister, J.F., 1955, Geology of mineral deposits in the Ubehebe Peak quadrangle, Inyo County, California: California Div. Mines and Geology Spec. Rept. 42, 63 p.
- McAllister, J.F., 1956, Geology of the Ubehebe Peak quadrangle, California: U.S. Geol. Survey Map GQ-95, scale 1:62,500.

- McAllister, J. F., 1970, Geology of the Furnace Creek borate area, Death Valley, Inyo County, California: California Div. Mines and Geology Map Sheet 14, scale 1:24,000.
- McKee, E. H., and Nelson, C. A., 1967, Geologic map of the Soldier Pass quadrangle, California and Nevada: U. S. Geol. Survey Map GQ-654, scale 1:62,500.
- McKee, E. H., 1968, Geology of the Magruder Mountain area, Nevada-California: U. S. Geol. Survey Bull. 1251-H, 40 p.
- McKee, E. H., 1968, Age and rate of movement of the northern part of the Death Valley-Furnace Creek fault zone, California: Geol. Soc. America Bull. v. 79, p. 509-512.
- Nelson, C. A., 1966, Geologic map of the Blanco Mountain quadrangle, Inyo and Mono Counties, California: U. S. Geol. Survey Map GQ-529, scale 1:62,500.
- Nelson, C. A., 1966, Geologic map of the Waucoba Mountain quadrangle, Inyo Co., California: U. S. Geol. Survey Map GQ-528, scale 1:62,500.
- Nelson, C. A., 1971, Geologic map of the Waucoba Spring quadrangle, Inyo Co., California: U. S. Geol. Survey Map GQ-921, scale 1:62,500.
- Noble, D. C., 1968, Kane Springs Wash volcanic center, Lincoln County, Nevada, in Eckel, E. B., ed., Nevada Test Site: Geol. Soc. America Memoir 110, p. 109-116.
- Norman, L. A., Jr., and Stewart, R. M., 1951, Mines and mineral resources of Inyo County: California Jour. Mines and Geology, v. 47, p. 17-223.
- Ransome, F. L., 1909, The geology and ore deposits of Goldfield, Nevada: U. S. Geol. Survey Prof. Paper 66, 258 p.
- Ransome, F. L., 1923, Geology of the Oatman gold district, Arizona: A preliminary report: U. S. Geol. Survey Bull. 743, 58 p.
- Rinehart, C. D., and Ross, D. C., 1956, Economic geology of the Casa Diablo Mountain quadrangle, California: California Div. Mines Spec. Rept. 48, 17 p.
- Rinehart, C. D., Ross, D. C., and Pakiser, L. C., 1964, Geology and mineral deposits of the Mount Morrison quadrangle Sierra Nevada, California; With a section on a gravity study of Long Valley: U. S. Geol. Survey Prof. Paper 385, 106 p.

- Robinson, P.T., McKee, E.H., and Moiola, R.J., 1968, Cenozoic volcanism and sedimentation, Silver Peak region, western Nevada and adjacent California, in Coats, R.R., Hay, R.L., and Anderson, C.A., eds., Studies in volcanology: Geol. Soc. America Memoir 116, p. 577-611.
- Rogers, T.H., 1967, Geologic map of California, San Bernardino sheet, Olaf P. Jenkins edition: California Div. Mines and Geology, scale 1:250,000.
- Ross, D.C., 1961, Geology and mineral deposits of Mineral County, Nevada: Nevada Bur. Mines and Geology Bull. 58, 98 p.
- Ross, D.C., 1965, Geology of the Independence quadrangle, Inyo County, California: U.S. Geol. Survey Bull. 1181-0, 64 p.
- Ross, D.C., 1967, Geologic map of the Waucoba Wash quadrangle, Inyo County, California: U.S. Geol. Survey Map GQ-612, scale 1:62,500.
- Ross, D.C., 1967, Generalized geologic map of the Inyo Mountains region, California: U.S. Geol. Survey Map I-506, scale 1:125,000.
- Ross, D.C., 1970, Pegmatitic trachyandesite plugs and associated volcanic rocks in the Saline Range-Inyo Mountains region, California: U.S. Geol. Survey Prof. Paper 614-D, 29 p.
- Schrader, F.C., 1909, Mineral deposits of the Cerbat Range, Black Mountains, and Grand Wash Cliffs, Mohave Co., Arizona: U.S. Geol. Survey Bull. 397, 226 p.
- Smith, A.R., 1964, Geologic map of California, Bakersfield sheet, Olaf P. Jenkins edition: California Div. Mines and Geology, scale 1:250,000.
- Smith, G.I., Troxel, B.W., Gray, C.H., and von Huene, Roland, 1968, Geologic reconnaissance of the Slate Range, San Bernardino and Inyo Counties, California: California Div. Mines and Geol. Spec. Rept. 96, 33 p.
- Stokes, W.L., and Heylmun, E.B., 1963, Tectonic history of southwestern Utah, in Heylmun, E.B., ed., Guidebook to the geology of southwestern Utah: Intermountain Assoc. Petroleum Geologists Guidebook 12, p. 19-25.
- Strand, R.G., 1967, Geologic map of California, Mariposa sheet, Olaf P. Jenkins edition: California Div. Mines and Geology, scale 1:250,000.

- Threet, R. L., 1963, Structure of the Colorado Plateau margin near Cedar City, Utah, in Heylman E. B., ed., Guidebook to the geology of southwestern Utah: Intermountain Assoc. Petroleum Geologists Guidebook 12, p. 104-117.
- Troxel, B. W., and Morton, P. K., 1962, Mines and mineral resources of Kern County, California: California Div. Mines and Geology, County Rept. no. 1, 370 p.
- Tschanz, C. M., and Pampeyan, E. H., 1970, Geology and mineral deposits of Lincoln County, Nevada: Nevada Bur. Mines and Geology Bull. 73, 187 p.
- Volborth, Alexis, 1973, Geology of the granite complex of the Eldorado, Newberry, and northern Dead Mountains, Clark County, Nevada: Nevada Bur. Mines and Geology Bull. 80, 40 p.
- Wilson, E. D., Moore, R. T., and Cooper, T. R., 1969, Geologic map of Arizona: U.S. Geol. Survey, scale 1:500,000.
- Young, R. A., and Brennan, W. J., 1974, Peach Springs Tuff: Its bearing on structural evolution of the Colorado Plateau and development of Cenozoic drainage in Mohave County, Arizona: Geol. Soc. America Bull., v. 85, p. 83-90.

#### References Used in Compiling Plate 2:

- Albers, J. P., and Kleinhampl, F. J., 1970, Spatial relation of mineral deposits to Tertiary volcanic centers in Nevada: U.S. Geol. Survey Prof. Paper 700-C, p. C1-C10.
- Albers, J. P., and Stewart, J. H., 1972, Geology and mineral deposits of Esmeralda County, Nevada: Nevada Bur. Mines and Geology Bull. 78, 80 p.
- Anderson, R. E., 1969, Notes on the geology and paleohydrology of the Boulder City pluton, southern Nevada: U.S. Geol. Survey Prof. Paper 650-B, p. B35-B40.
- Anderson, R. E., 1973, Large-magnitude late Tertiary strike-slip faulting north of Lake Mead, Nevada: U.S. Geol. Survey Prof. Paper 794, 18 p.

- Bassett, A.M., and Kupfer, D.H., 1964, A geologic reconnaissance in the southeastern Mojave Desert, California: California Div. Mines and Geol. Spec. Rept. 83, 43 p.
- Bayly, Brian, 1968, Introduction to petrology: Englewood Cliffs, New Jersey, Prentice-Hall Inc., 371 p.
- Bishop, C.C., 1963, Geologic map of California, Needles sheet, Olaf P. Jenkins edition: California Div. Mines and Geology, scale 1:250,000.
- Carlson, J.E., and Willden, Ronald, 1968, Transcontinental Geophysical Survey (35°-39° N) geologic map from 112° W longitude to the coast of California: U.S. Geol. Survey Misc. Geologic Inv. Map I-532-C, scale 1:1,000,000.
- Cook, E.F., 1960, Geologic atlas of Utah, Washington County: Utah Geol. and Mineralog. Survey Bull. 70, 124 p.
- Cornwall, H.R., 1972, Geology and mineral deposits of southern Nye County, Nevada: Nevada Bur. Mines and Geology Bull. 77, 49 p.
- Davis, G.A., February 1974, unpub. mapping.
- Dibblee, T.W., Jr., 1967, Areal geology of the western Mojave Desert, California: U.S. Geol. Survey Prof. Paper 522, 153 p.
- Ekren, E.B., Anderson, R.E., Rogers, C.L., and Noble, D.C., 1971, Geology of northern Nellis Air Force Base Bombing and Gunnery Range, Nye County, Nevada: U.S. Geol. Survey Prof. Paper 651, 91 p.
- Gilbert, C.M., Christensen, M.N., Al-Rawi, Yehya, and Lajoie, K.R., 1968, Structural and volcanic history of Mono Basin, California-Nevada, in Coats, R.R., Hay, R.L., and Anderson, C.A., eds., Studies in volcanology: Geol. Soc. America Memoir 116, p. 275-329.
- Hintze, L.F., 1963, Geologic map of southwestern Utah: Utah Geol. and Mineralog. Survey, scale 1:250,000.
- Jennings, C.W., 1958, Geologic map of California, Death Valley sheet, Olaf P. Jenkins edition: California Div. Mines and Geology, scale 1:250,000.
- Jennings, C.W., 1961, Geologic map of California, Kingman sheet, Olaf P. Jenkins edition: California Div. Mines and Geology, scale 1:250,000.

- Jennings, C.W., Burnett, J.L., and Troxel, B.W., 1962, Geologic map of California, Trona sheet, Olaf P. Jenkins edition: California Div. Mines and Geology, scale 1:250,000.
- Jennings, C.W., and Strand, R.G., 1969, Geologic map of California, Los Angeles sheet, Olaf P. Jenkins edition: California Div. Mines and Geology, scale 1:250,000.
- Koenig, J.B., 1963, Geologic map of California, Walker Lake sheet, Olaf P. Jenkins edition: California Div. Mines and Geology, scale 1:250,000.
- Longwell, C.R., Pampeyan, E.H., Bowyer, B., and Roberts, R.J., 1965, Geology and mineral deposits of Clark County, Nevada: Nevada Bur. Mines and Geology Bull. 62, 218 p.
- Matthews, R.A., and Burnett, J.L., 1965, Geologic map of California, Fresno sheet, Olaf P. Jenkins edition: California Div. Mines and Geology, scale 1:250,000.
- Noble, D.C., 1968, Kane Springs Wash volcanic center, Lincoln County, Nevada in Eckel, E.B., ed., Nevada Test Site: Geol. Soc. America Memoir 110, p. 109-116.
- Robinson, P.T., McKee, E.H., and Moiola, R.J., 1968, Cenozoic volcanism and sedimentation, Silver Peak region, western Nevada and adjacent California, in Coats, R.R., Hay, R.L., and Anderson, C.A., eds., Studies in volcanology, p. 577-611.
- Rogers, T.H., 1967, Geologic map of California, San Bernardino sheet, Olaf P. Jenkins edition: California Div. Mines and Geology, scale 1:250,000.
- Smith, A.R., 1964, Geologic map of California, Bakersfield sheet, Olaf P. Jenkins edition: California Div. Mines and Geology, scale 1:250,000.
- Strand, R.G., 1967, Geologic map of California, Mariposa sheet, Olaf P. Jenkins edition: California Div. Mines and Geology, scale 1:250,000.
- Tschanz, C.M., and Pampeyan, E.H., 1970, Geology and mineral deposits of Lincoln County, Nevada: Nevada Bur. Mines and Geology Bull. 73, 187 p.
- Volborth, Alexis, 1973, Geology of the granite complex of the Eldorado, Newberry, and northern Dead Mountains, Clark County, Nevada: Nevada Bur. Mines and Geology Bull. 80, 40 p.
- Wilson, E.D., Moore, R.T., and Cooper, T.R., 1969, Geologic map of Arizona: U.S. Geol. Survey, scale 1:500,000.